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Single-Station Forecasting with Interactive Computer Systems

by

Carlyle H. Wash

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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ABSTRACT

A review of classical single-station analysis and forecast techniques is presented. Enhancements to these classical procedures are outlined. These improvements are possible through the existence of interactive computer capabilities and effective use of satellite and numerical weather prediction forecast aids.

I. Introduction

The rapid advance of interactive computer systems provides many opportunities to assist the synoptic meteorologist in giving improved environmental support. These systems permit computer-managed data sets, the presentation of integrated displays of surface, upper-air, satellite and/or radar data and the computation of derived parameters and simple models to assist forecast decisions. All major national meteorological services are developing prototype interactive systems. The Tactical Environmental Support System (TESS), developed for the U.S. Navy, is already in use in the fleet in preliminary form (Jarrett and Brand, 1986). A more sophisticated version, TESS (3), will be introduced by the end of the decade.

These interactive systems can dramatically enhance the effectiveness of the meteorological watch section on a major ship, airfield or regional forecast facility. Major components of these improvements include both software and hardware tools to facilitate the enhanced productivity of the forecaster.

Single-station forecasting is one of the program modules planned for TESS (3). Single-station analysis and forecasting is defined by the Glossary of Meteorology (Huschke, 1959) to be

> "The analysis of the weather pattern from more or less continuous meteorological observations made at a single geographic location. The extension of these techniques to produce a weather forecast is known as single-station forecasting."

This definition reflects the World War II use of local surface and upper-air data to prepare a 24-48 h forecast. Some projects are underway to use interactive computer techniques to automate these classical single-station analysis and forecasting techniques (Jasperson et al, 1987).

This report addresses single-station forecast approaches for TESS (3) or similar interactive systems at a remote location. It is argued that classical rules need to be complemented with satellite and numerical weather prediction (NWP) tools in practice of single-station forecasting with interactive computers. Not to do so would ignore a number of major changes over the past three decades in the practice of synoptic meteorology.

Today, most on-site meteorologists, no matter how remote, have access to satellite imagery to supplement their local observations. Inferences of synoptic-scale and meso-scale patterns from satellite imagery certainly should be included in a single-station forecast approach. A second major forecasting advance is the development of reliable short-range numerical weather prediction for synoptic-scale systems. Currently, numerical forecasts are generally quite accurate in the 48-72 h period. For short period communication interruptions, previous model runs still would be a valuable source of forecast guidance.

Modern satellite systems also provide temperature and moisture profile data from selected infrared and microwave regions. These data, now used by the central site global analyses, are available for local minicomputer processing and use in local analyses. Having significant desk-top computer power available also will allow the synoptic meteorologist to execute simple models to aid local forecast decisions.

These major changes radically change the meaning of single-station forecasting. The goals of this report are to outline a current definition for single-station forecasting for the TESS (3) or other minicomputer-equipped remote stations and to outline the development work needed to realize these capabilities.

This report will first review classic single-station forecasting and examine some current implementations. Next, the new developments in synoptic meteorology will be reviewed and their use within a modern TESS single-station forecast module explored. Finally a list of specific tasks is presented to fully realize the potential of TESS (3) for single-station forecasting.

II. Classic Single-Station Analysis and Forecasting

The classic single-station analysis and forecasting uses careful time-section analysis of surface and upper-air rawinsonde data to infer the synoptic pattern and the location of your station in the pattern. Vertical profiles of temperature, dew point and wind plotted on adiabatic and other diagrams aid in the analysis. The forecast is based on determining the movement and intensity changes of the inferred synoptic pattern. Excellent references for these classical techniques are Oliver and Oliver (1945), Rossby et al (1942), U.S. Navy (1955), and Starr (1942).

Table 1

Diagrams for Classic Single-Station Forecasts

Chart	Parameters
Adiabatic diagrams	Vertical temperature, moisture profiles
Hodographs (Polar Diagram)	Vertical wind shear
Time-Sections of Upper-Air and Surface Data	Temporal structure of wind, temperature, moisture and geopotential height data (Enhanced with surface weather data)

Oliver and Oliver (1945) and Starr (1942) present a procedural outline for single-station forecasting using the above charts. First, the most probable circulation pattern aloft (700 mb and 500 mb) is estimated. The type of air-mass over the station is determined from vertical temperature and moisture structure and the stability analyses. The air-mass type gives some indication of upper-air pattern if the air-mass source regions are known for a particular area. The temperature and height of the tropopause also provides air-mass information. A cold, high troposphere indicates a tropical air mass while a warm, low troposphere is found with shallow polar air masses.

The vertical wind measurements can estimate the 700 mb and 500 mb height gradients and the location of ridges and troughs near the station. The vertical wind shear indicates the horizontal temperature gradient and the direction of the coldest air in the low, middle and upper troposphere. Comparison of winds, wind shears and thicknesses to monthly normals indicates the relative intensity of the current weather system.

The time-section analysis of temperatures, heights and winds indicate the structure of the large scale flow as well as the frequency of shorter wave systems. A method to determine the wavelength and speed of the short waves by removing the large scale flow is presented in the U.S. Navy manual (1955). Long periods of pronounced northerly or southerly flow occur only with large amplitude long wave patterns. Time variations of temperature, height or wind directions from the long term mean reveal passage of transient short wave disturbances.

For the sea level analysis, the frictional and gradient wind relations indicate the surface pressure gradient over the station and the probable location of surface systems near the station. The time variation of surface and boundary layer winds then indicate the movement of surface systems with respect to the station.

Frontal locations can be determined by a number of methods. The vertical sounding will indicate frontal inversions. Warm frontal inversions and over-running warm air indicate approach of a warm front and a cyclone. Lowering of the inversion with typical warm frontal slope will indicate time of frontal passage. Surface cloud observations should agree with this analysis. Cold fronts can be displaced east of the station using the speed of the wind in the cold air.

All of these observations are used to construct probable surface and 500 mb charts for an area immediately around the station. The time variation of these analyses will provide movement information of weather systems and are used in forecasting associated weather patterns. The goal of classical single-station analysis and forecasting is determining where your station is in the synoptic pattern and how that pattern is changing.

III. Current Sources of Data for Modern Single-Station Forecasting

Meteorology has changed dramatically over the past three decades. Observational techniques and theoretical and computer modelling techniques have rapidly advanced. A single-station analysis and forecast capability for interactive computer systems like TESS (3) must be organized to effectively utilize these developments.

Satellite Imagery. The local receipt of satellite imagery by a remote site represents a major expansion of the local observation base. The meteorologist viewing horizon expands from line-of-sight (~30 km) to ~1500 km or further. Operational satellite imagery must be included with in-situ observations in the single-station forecasting scenarios.

A survey of current Navy satellite receivers indicates wide variation of capabilities due to differing systems (SMQ-6 for NOAA APT and SMQ-10 for DMSP OLS). See Appendix A for acronym definitions. This confusing situation will be improved with the deployment of the SMQ-11 over the next four years. The SMQ-11 will receive NOAA high resolution imagery (HRPT), DMSP OLS and analog re-transmitted imagery from GOES-type geostationary satellites (GOES-WEFAX). Also, it will be the source of satellite data for TESS (3), including possible NROSS data.

The TESS (3) forecast system equipped with an SMQ-11 satellite receiver then will receive digital imagery for both NOAA and DMSP polar-orbiters plus processed imagery sectors or mosaics from GOES Weather Facsimile (WEFAX). With two operational NOAA and two DMSP satellites, TESS would have potentially four daylight and four nighttime scenes available with a time interval of 3 h.

Satellite Soundings, Winds and Data Collection. In addition to imagery, both NOAA and DMSP satellites have vertical temperature and moisture profile instruments on-board. These data are embedded in the high resolution imagery data stream and would be available to a remote computer-equipped satellite receiving station. The satellite sounding coverage of the typical two passes is depicted by Fig. 1. Sounding retrieval algorithms are available on minicomputer systems to convert the radiance data into temperature and moisture profiles. The Navy's Oceanography Command Detachment at McMurdo Station, Antartica, will use an interactive computer system to process satellite soundings in the next operation season, starting late 1987.

Both the NOAA and DMSP future sounding programs will be emphasizing measurements at microwave frequencies. This eliminates the need to correct for the amount of cloudiness in infrared soundings. Another application of these data is

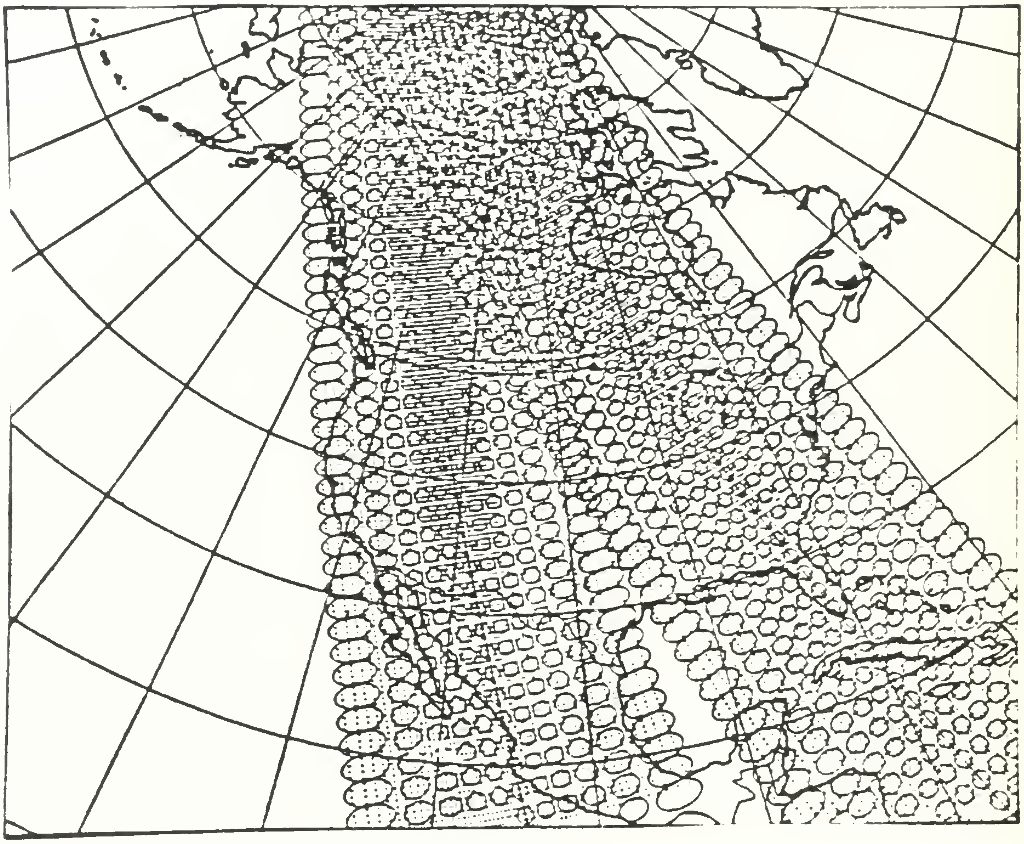

Fig. 1 - Scanner coverage area for TIROS-N High Resolution Sounder (HIRS) and Microwave Scanning Unit (MSU) showing two consecutive orbits (Smith et al, 1979).

the display of a particular sounder channel. This provides an approximate temperature field for the layer in the vertical where the sounder weighting function is maximized. Fig. 2 presents an example of this type of data from Hayden (1979). Moisture channel data (6.7 μM) from GOES are being utilized in this manner also by the National Weather Service.

Another successful capability of the meteorological satellites is the use of data collection packages to receive and rebroadcast data messages from remote measurement platforms such as fixed and drifting buoys and ships at sea. A current example is the French ARGOS system on the NOAA polar-orbiters. At NPS, an ARGOS local receiver copies drifting and fixed buoy and ship data in real time from the Gulf of Mexico and eastern Pacific Ocean. The single-station TESS (3) should be equipped to receive these data to expand its regional data base.

Wind data from satellites have been obtained from cloud feature tracking using geostationary imagery. It is unlikely digital geostationary data with sufficient time resolution for cloud tracking would be available for the TESS (3) system. However, the NASA scatterometer planned for NROSS and the European scatterometer on ERS will provide 50 km resolution wind surface data over a significant area about the ground track. These data will be of significant use in doing regional surface and boundary layer analyses.

Numerical Weather Prediction. The development of sophisticated numerical weather prediction (NWP) models has dramatically changed weather forecasting. These models have significant skill

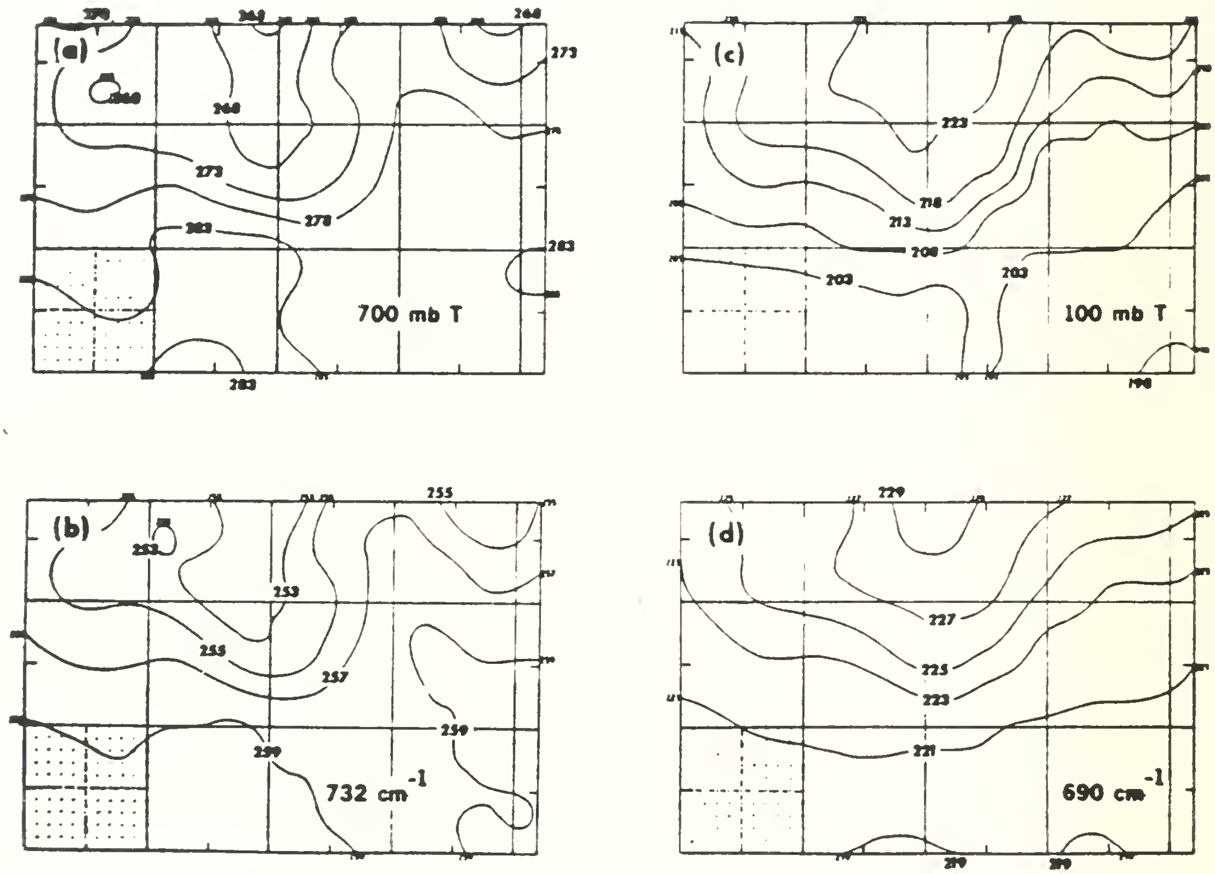

Fig. 2 - Horizontal fields of brightness temperatures (calculated from temperature analyses) for frequencies 690 cm^{-1} (d) and 732 cm^{-1} (b) which have principal sensitivity to temperatures near 100 mb (c) and 700 mb (a) respectively (Hayden, 1979).

in forecasting synoptic-scale systems through 48-72 h and measurable skill at 5-7 days in forecasting the 500 mb height field (American Meteorological Society, 1983; Anthes, 1983). Also, considerable effort has been placed on the development of statistical forecasts of weather elements from NWP predictions. This extension of skill means a forecast run is usable for at least 24 h after its preparation. In fact on many carriers at sea, 12 h prognoses are displayed and used as analyses because of the delays in broadcasting all of the FNOC mandatory analyses. Older forecast runs are also a valuable resource for single-station forecasting when a communication is lost for a short (1-2 days) period of time.

Local Computer Analyses and Models. Finally, the presence of a minicomputer in the weather office will enhance the display and utility of all of the data types listed above. Time intensive analyses such as time and space cross-sections become working tools rather than academic exercises. Sounding plots, hodographs and stability calculations can be completed by the computer rather than the watch section. Even NWP output can be placed in forecaster-designed displays for briefing and forecast analysis. The local computer can provide tailored statistical forecasts also. Recently, Miller and Leslie (1984) reported encouraging results using second-order Markov models on historical data to forecast clouds and precipitation up to 12 h in advance. The computer, using menus, can also assist less experienced watch section personnel in focusing on the right analyses and approaches for the problem at hand.

IV. A Future Single-Station Forecast Program

In order to provide the best possible support, the single-station forecast algorithms must be integrated with other data bases and applications of TESS. In this section a plan is outlined which addresses TESS (3) forecaster support for a wide range of operational conditions. Situations when the remote site has no communication with central weather center and/or meteorological satellites are addressed.

A logical organization of data sources, archives, analyses and forecasts for a remote TESS (3) user is summarized by Fig. 3. The data base to support TESS single-station forecasting is organized into four divisions, each with its own archive:

(1) Central site analyses and forecasts. This includes all FNOC analysis and forecast fields prepared with sophisticated data assimilation, numerical weather prediction and statistical techniques. Also included may be products for other weather central sites (e.g. NMC, ECMWF, JMA) using the digital transmission of central site analyses and forecasts by satellite.

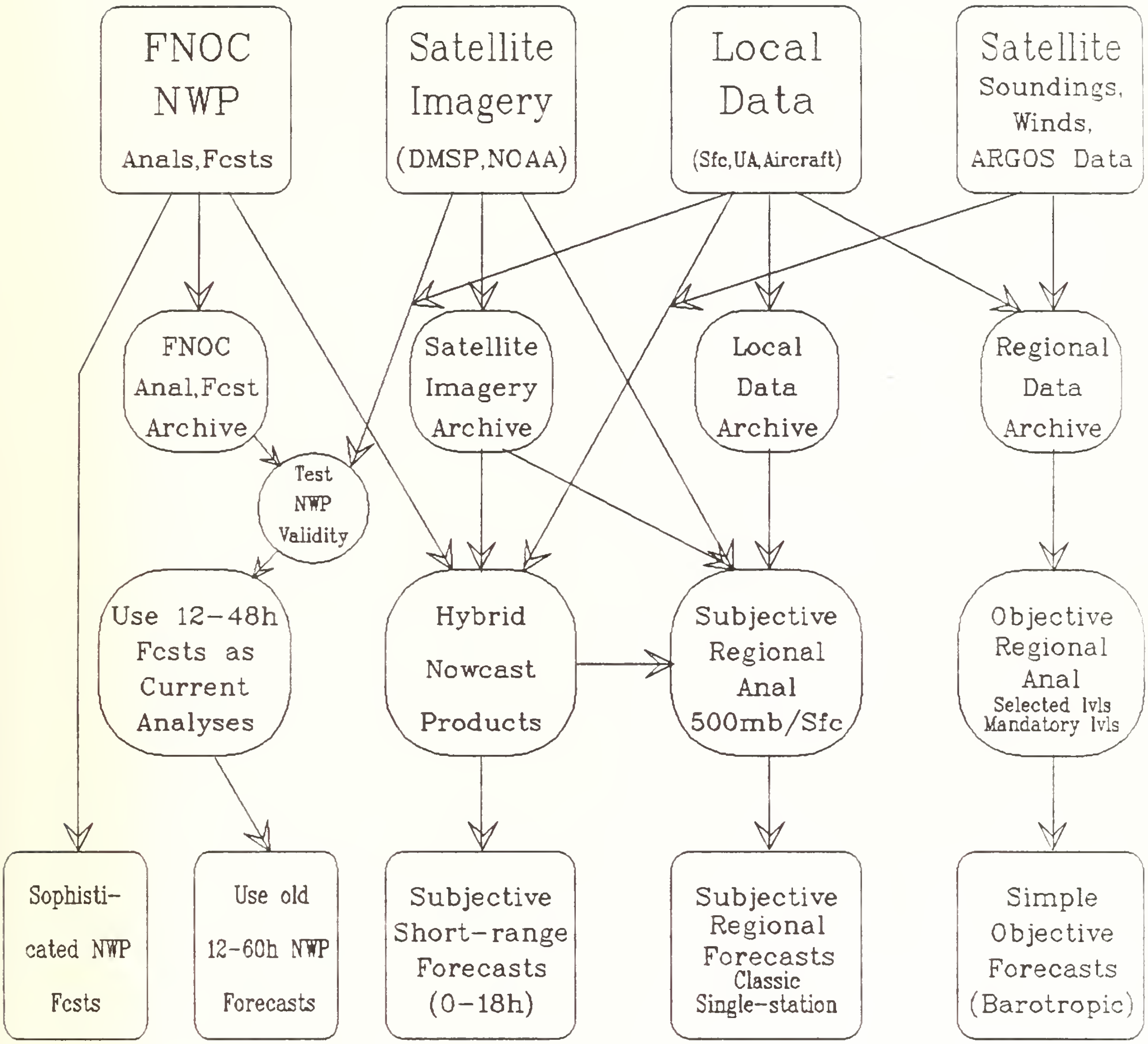

Fig. 3 - Flow chart for data, archives, analyses and forecasts for remote interactive computer TESS forecasting.

(2) Satellite imagery. This includes all visual, infrared and microwave imagery from NOAA and DMSP satellites. It may also include GOES-WEFAX if its coverage and timeliness is better than polar-orbiter data.

(3) Local data. All data from the remote station or ship (surface and upper air) plus observations from other ships in the battlegroup and/or nearby island and/or shore locations are stored here. It will include aircraft pilot reports, as available.

(4) Regional data. All data from satellite, radio teletype and other sources covering the local region (2000 km radius) of the remote station or ship are stored under this category. It will include satellite sounding passes, rebroadcast of data by satellite (ARGOS) and future quantitative satellite data (e.g. NROSS or ERS scatterometer).

The length of the archive for each data base is determined by their use by the forecaster.

A. Complete Communication

In a normal situation, all sources of data would be available. The forecaster would rely on the state-of-the-art NWP analyses and forecasts for the synoptic-scale forecast guidance. This is complemented by the model output statistics (MOS) forecast of weather elements. For the short-range (0-18 h), local (mesoscale) forecast, satellite imagery and local data play a greater role. TESS (3) display capabilities and access to satellite imagery and computer-managed data bases will permit the preparation of "nowcast" type products for the forecaster. The local forecast, including many key weather elements critical to aviation, is done subjectively using those nowcast tools based on satellite data, local and regional data. Another nowcast aid is the Navy Over-Water Local Atmospheric Prediction System (NOWLAPS) developed by NEPRF (Ardanuy, 1986). The system is the higher order closure model of Burk and Thompson (1982) converted to run on the Navy TESS computers. Large scale FNOC fields and forecasts (or local soundings) are used to initialize the model which then provides high resolution boundary-layer forecasts.

While the NWP component of the forecast products is relatively well-known today with facsimile broadcast of NWP charts, a number of nowcast products is now emerging from the research community. These hybrid nowcast products require the processing and video-display power of the microcomputer planned for TESS (3). Note that the "nowcast products" receive data from all four data bases (Fig. 3). Application programs and displays envisioned for this short-range forecasts support are listed on Table 2.

Table 2

Nowcasting Analyses and Displays Using Interactive Computer Processing

(1) Cross-section analysis from rawinsonde data - for frontal analysis, aviation analysis forecasting (Clear-Air Turbulence (CAT), icing, contrails, cloudiness analysis).

(2) Cross-section analysis on NWP model data - for forecast frontal structure and aviation briefing.

(3) Cross-section analysis on satellite sounding data- for vertical atmospheric structure analysis at sea.

(4) Time-section analysis of observed data - to determine trends in cloud ceiling, visibilities, winds, etc.

(5) Time-section analysis for numerical and statistical forecast data. See Fig. 4 for an example.

(6) Rawinsonde temperature, dew point and wind plot.

(7) Specialized rawinsonde analyses:
- (a) Hodograph
- (b) Stability indices
- (c) Display of temporal changes over 6 h, 12 h, 24 h
- (d) Cloud calculations; lifting condensation level, cloud tops,probable cloud layers, level of free convection.

(8) Horizontal weather depiction analyses from multi-channel satellite data. See Wash et al (1987) for examples from visual and infrared data. Microwave imagery from DMSP SSM/I will further enhance these products.

(9) Plots of local and regional data with satellite imagery.

(10) Specialized plots for specific tasks:
(a) Cloud-visibility plot for aviation forecasting:
- (i) Cloud amount
- (ii) Cloud layers
- (iii) Visibility
- (iv) Weather
- (v) Past weather
- (vi) Cloud types
- (vii) Cloud remarks.

(b) Frontal location plots:
    (i) Temperature
    (ii) Dew Point
    (iii) Wind
    (iv) Pressure and pessure change
    (v) Weather.

(11) Regional upper-air plots:
    (a) Rawinsonde only
    (b) Rawinsonde plus other data types; satellite sounding, aircraft, etc.

(12) Display of FNOC analyses on the satellite images with or without local data.

(13) Conditional climatology guidance from historical data base and time series of local observations.

All of the above utilize the interactive computer's capability to display various types of meteorological data together and produce, through graphics and imagery, useful data and analysis displays. Normal forecast decisions with full communications are fully supported by forecast boxes 1 and 2 on Fig. 3.

B. Partial Communications

Communication and equipment failures can disrupt receipt of products and data by a ship or remote station. It is important that contingencies be prepared for these interruptions. This planning and the use of the interactive microcomputer to create replacement analyses and forecasts constitute modern single-station forecasting.

Loss of FNOC Communication. A loss of FNOC communication eliminates central site analyses and NWP forecasts. This situation is depicted by Fig. 5. Short-range forecast support is not seriously affected as the nowcast products are still

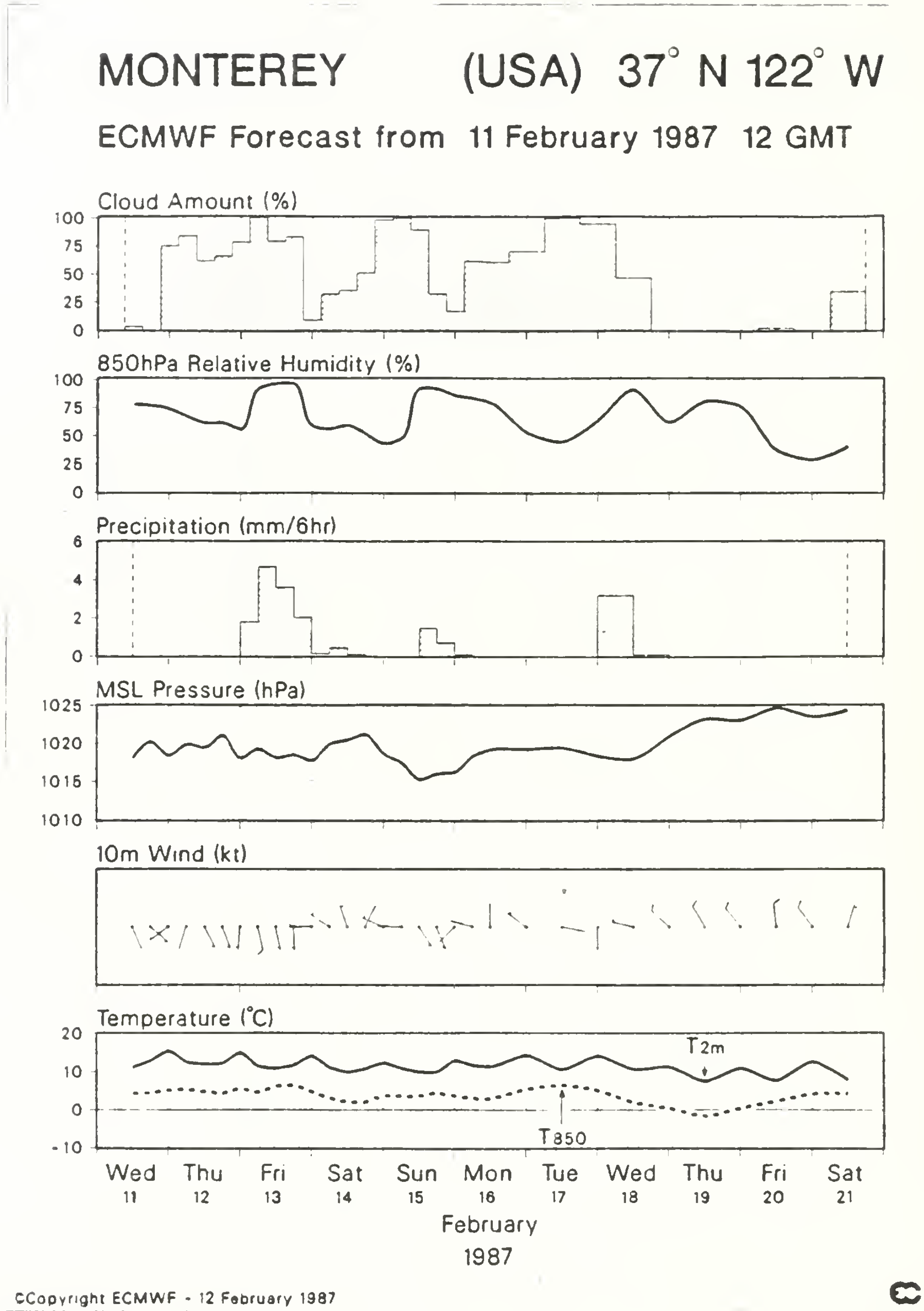

Fig. 4 - Forecasting elements displayed in time section form from European Center for Medium Range Forecasting.

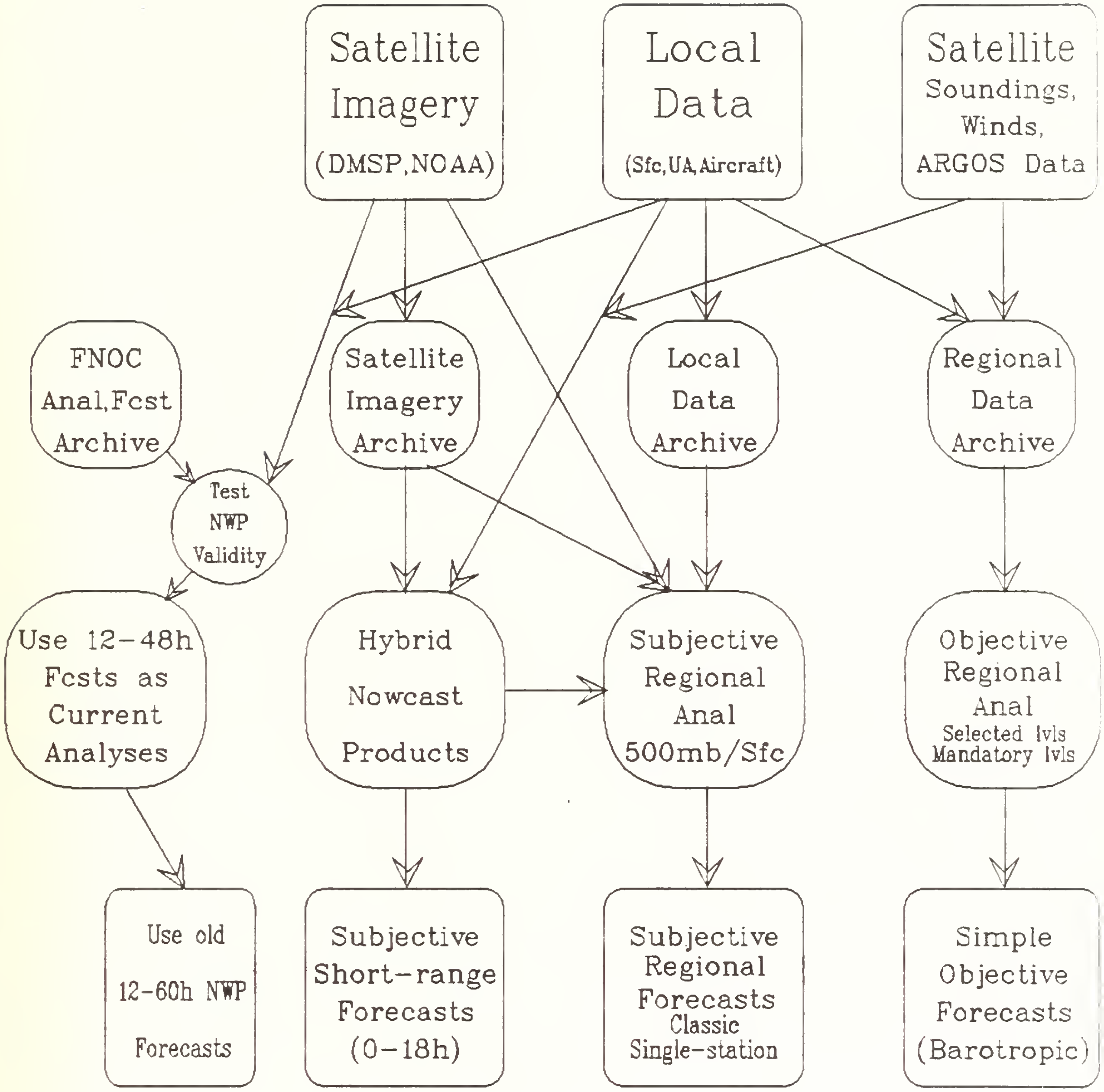

Fig. 5 - Flow chart for TESS forecasting with short term loss of communication with FNOC.

available. For synoptic-scale forecasts longer than 24 h, the first approach is to use the last available NWP and MOS forecasts. For a short communication interruption, these forecasts would still provide skillful 1-3 day guidance in most situations.

These older NWP and MOS forecasts should be used with caution. Satellite data and local observations should be used to check the validity of a NWP forecast run to ensure that the model run solution is reasonably close to the actual atmosphere. Table 3 presents satellite features that can be used to check NWP forecasts. If valid, appropriate older forecasts can be used as analyses and following forecasts will guide the synoptic outlooks.

When the FNOC forecast archive ceases to be a viable source of guidance, satellite and local data bases become much more important. In this situation (depicted by Fig. 6), the TESS (3) can do regional objective analyses for selected levels (e.g. 500 mb and 300 mb) or for all mandatory levels to provide timely three-dimensional analyses. Data for these analyses would come from satellite soundings, rebroadcast data from buoys, ships and aircraft (ARGOS) as well as local data.

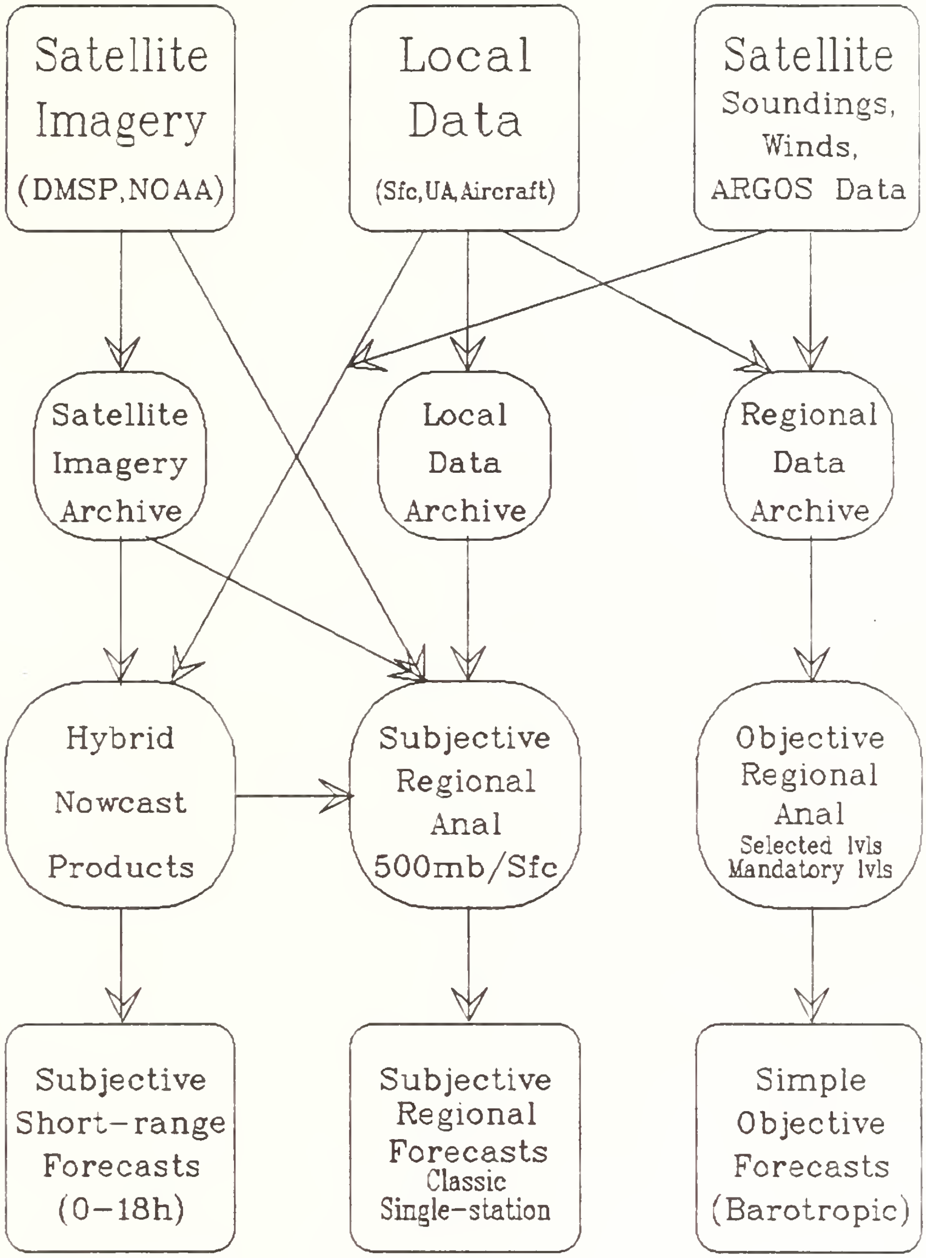

Fig. 6 - Flow chart for TESS forecasting with extended FNOC communication interruption and no viable FNOC forecast archive.

Table 3

Satellite Observed Cloud Features for NWP Analysis Validation

	Synoptic Feature	Cloud Signature	Associated NWP Analysis Fields
1.	Cold Front	Organized bands of multiple layer clouds, rope cloud, variations of cloud tops along the front	Bands of high relative humidity in all or lower layers of model (dependent on cloud depth), SLP trough, warm edge of the thickness gradient
2.	Frontal Wave Development	Bulge in frontal cloud pattern, area of enhanced frontal cloudiness	SLP low on the front, warm ridge in the thickness field
3.	Strong Long Wave Ridge	Generally N-S edge to frontal cloudiness, anticyclonic turning to cirrus transversing the ridge	500 mb ridge line, minimum vorticity center
4.	Oceanic Short Wave Trough (Small Amplitude)	Enhanced convective cumulus under the PVA area ahead of the trough line, clearing and suppressed cumulus behind the trough line	Small amplitude 500 mb trough, centers of positive vorticity
5.	Oceanic Short Wave Trough (Moderate Amplitude)	Comma cloud, formation of frontal band south of comma head	Moderate amplitude 500 mb trough, SLP trough, distinct vorticity center and PVA area
6.	Short Wave Ridge	Leading edge of comma cloud	500 mb short wave ridge, minimum vorticity center

7.	Short Wave Trough Line	Sharp change in cloud structure along a cold frontal band	Location of short wave trough line over the front
8.	Oceanic Cold Advection behind Cold Front	Open-cell cloud field and structure of cells indicate strength of the low tropospheric wind field	Cold air advection indicated by SLP, thickness field, 850 mb (700 mb) height or wind and temperature field
9.	Coastal Cold Advection Wind Field	Cloud streets as clouds form in the destabliized continental polar air	Coastal surface wind, SLP gradient
10.	Oceanic Warm Advection in Low Troposphere	Closed cell, stratiform cloud pattern	Warm air advection indicated by SLP/chart thickness or 850 mb wind and Temp
11.	Subtropical High Pressure Ridge Line	Cloudiness change due to advection differences	Axis of SLP anticyclone
12.	Polar and Subtropical Jet Stream	Canopy of cirrus moving eastward, transverse banding in cirrus	Jet axis north of cirrus shield
13.	Developing Extratropical Cyclones	Large comma, distinct dry slot	SLP cyclone center
14.	Mature Cyclone	Cyclonicly curved cloud bands, old cold vortex	Location of SLP and 500 mb center

The local microcomputer also could execute simple objective forecasts from these analyses. Examples include barotropic and two-level quasi-geostrophic models (Holton, 1979). Regional analysis and forecast cycle could continue as long as reasonable regional data base was available.

A second source of synoptic guidance is the use of classic single-station analysis procedures. This approach is considerably enhanced by the availability of satellite imagery. Characteristics of the upper-level flow, amplitude of long waves, location of surface cyclones and anticyclones, presence of upper troposphere jet stream and other features are all derivable from current and past satellite imagery using satellite interpretation. A number of valuable rules from local analysis can be prepared by classic satellite imagery interpretation manuals such as Fett and Mitchell (1977) and others. The local data single-station methods discussed in Chapter II become considerably more effective with regional satellite imagery.

The subjective analysis also will benefit from the hybrid nowcast software described earlier. Time-section and hodograph displays of current and recent local data can be rapidly prepared using interactive computer methods. Short-range forecasts would still be prepared from nowcast products prepared from satellite imagery and local data.

C. Complete Communication Loss.

If satellite imagery, soundings and communication were lost, the subjective single-station analysis and forecast methods would be prepared as shown in Fig. 7. Note that the microcomputer time-section and rawinsonde products available in the nowcast section can automate the preparation of these forecast tools. Conditional climatology forecasts also could be completed using a historical data base of past weather sequences at a particular location and date(s).

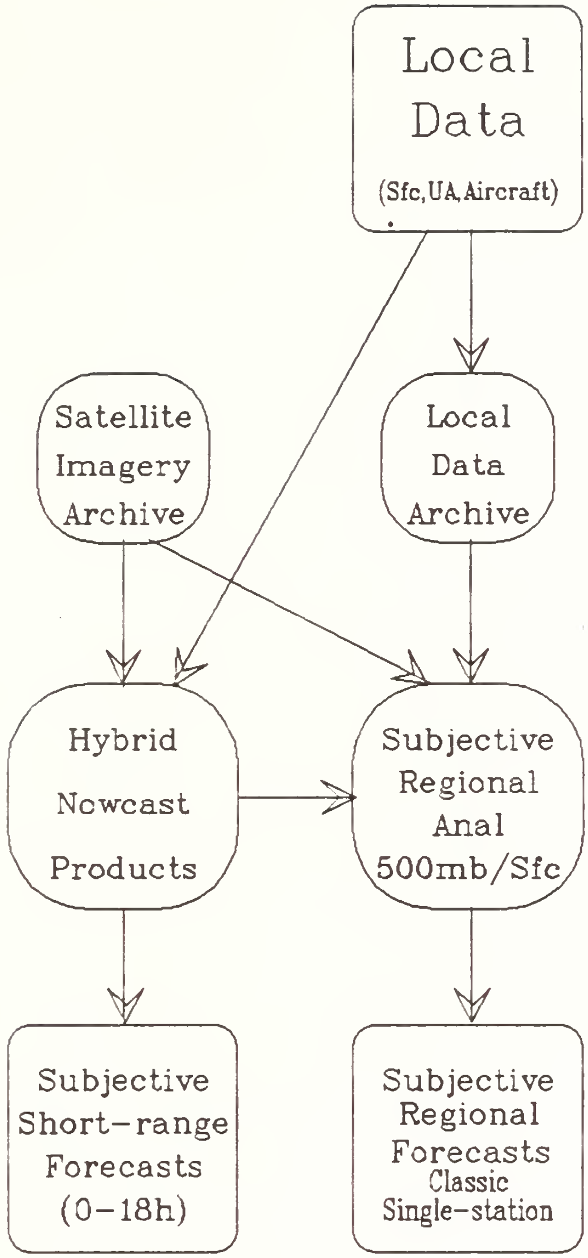

Fig. 7 - Flow chart for TESS forecasting without FNOC and satellite communication.

Single-station analysis and forecasting takes many forms when an interactive computer system, NWP, satellite imagery, regional and local data bases are available. The work station's capability to manage data sets, create new plots and briefing products, construct new analyses and forecasts, and produce hybrid displays of satellite, NWP and conventional data will produce a more effective remote ship or station analyses and forecasts.

In order to achieve the capability described by Fig. 3, the complete single-station analysis and forecast module, the following tasks need to be completed:

1. Develop and test the "nowcast" algorithms from Table 2
   a. Space cross-sections
   b. Time-sections
   c. Complete rawinsonde analysis and display
   d. Satellite, NWP, data plots sounding analysis

2. Apply time and space cross-section tools to NWP data

3. Acquire and test satellite sounding software

4. Implement and test analysis algorithms (successive-correction) for local analysis

5. Code and test barotropic and quasi-geostrophic forecast algorithms.

6. Develop procedures to test NWP model validity (using Table 3 for example)

7. Collect regional data via satellite relay.

8. Prepare satellite interpretation rules from a single-station perspective

9. Organize current and archive files for four data types

The addition of the above software in a minicomputer environment will substantially increase remote station forecaster capabilities.

V. Summary and Conclusions

The report investigates the meaning of single-station forecasting for today's synoptic meteorologists. Current advances in observational and dynamic meteorology have radically changed the meaning of single-station forecasting. The availability of accurate short-range forecasts, satellite data and desk-top computers enhance the capability of the remote and shipboard forecaster.

A processing plan to produce forecast products with various communication situations is outlined. Classic single-station forecasting is complemented by use of older (but still valid) forecast runs, nowcast analyses and regional local analyses plus simple model runs.

The lack of sufficient data and not enough analysis time is not the challenge of single-station analysis in the 1990s. The challenge is properly organizing the local data archives and interactive computer software to meet current forecasting demands, irregardless of current communication conditions with central site or with environmental satellites.

APPENDIX A

APT	-	Automatic Picture Transmission (NOAA)
ARGOS	-	French Data Collection and Platform Location System (NOAA)
DMSP	-	Defense Meteorological Satellite Program
ECMWF	-	European Center for Medium-Range Weather Forecasting
ERS	-	European Remote Sensing Satellite
GOES	-	Geostationary Orbiting Environment Satellite
HIRS	-	High Resolution Infrared Radiation Sounder (NOAA)
HRPT	-	High Resolution Picture Transmission (NOAA)
JMA	-	Japan Meteorological Agency
MSU	-	Microwave Sounding Unit (NOAA)
NMC	-	National Meteorological Center
NOAA	-	National Oceanic and Atmospheric Administration
NROSS	-	Navy Remote Ocean Sensing System
NWP	-	Numerical Weather Prediction
OLS	-	Operational Linescan System (DMSP)
SMQ-6	-	Ship-board satellite antenna and receiver for NOAA APT at 162 MHz
SMQ-10	-	Ship-board satellite antenna and receiver for DMSP data
SMQ-11	-	Future ship-board satellite antenna and receiver for both NOAA and DMSP data
SSM/I	-	Special Sensor Microwave/Imager
TESS	-	Tactical Environment Support System
WEFAX	-	Weather Facsimile

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